

APPENDIX G

SINGLE CONCENTRATION TOXICITY TEST - COMPARISON OF CONTROL WITH 100% EFFLUENT OR RECEIVING WATER

1. To statistically compare a control with one concentration, such as 100% effluent or the instream waste concentration, a t test is the recommended analysis. The t test is based on the assumptions that the observations are independent and normally distributed and that the variances of the observations are equal between the two groups.
2. Shapiro-Wilk's test may be used to test the normality assumption (See Appendix B for details). If the data do not meet the normality assumption, the nonparametric test, Wilcoxon's Rank Sum Test, may be used to analyze the data. An example of this test is given in Appendix F. Since a control and one concentration are being compared, the K = 1 section of Table F.5 contains the needed critical values.
3. The F test for equality of variances is used to test the homogeneity of variance assumption. When conducting the F test, the alternative hypothesis of interest is that the variances are not equal.
4. To make the two-tailed F test at the 0.01 level of significance, put the larger of the two variances in the numerator of F.

$$F = \frac{S_1^2}{S_2^2} \text{ where } S_1^2 > S_2^2$$

5. Compare F with the 0.005 level of a tabled F value with $n_1 - 1$ and $n_2 - 1$ degrees of freedom, where n_1 and n_2 are the number of replicates for each of the two groups.
6. A set of mysid growth data from an effluent (single concentration) test will be used to illustrate the F test. The raw data, mean and variance for the control and 100% effluent are given in Table G.1.
7. Since the variability of the 100% effluent is greater than the variability of the control, S^2 for the 100% effluent concentration is placed in the numerator of the F statistic and S^2 for the control is placed in the denominator.

$$F = \frac{0.00131}{0.000861} = 1.52$$

8. There are 8 replicates for the effluent concentration and 8 replicates for the control. Thus, both numerator and denominator degrees of freedom are equal to 7. For a two-tailed test at the 0.01 level of significance, the critical F value is obtained from a table of the F distribution (Snedecor and Cochran, 1980). The critical F value for this test is 8.89. Since 1.52 is not greater than 8.89, the conclusion is that the variances of the control and 100% effluent are homogeneous.

TABLE G.1. MYSID, *MYSIDOPSIS BAHIA*, GROWTH DATA FROM AN EFFLUENT (SINGLE CONCENTRATION) TEST

	Replicate								\bar{X}	S^2
	1	2	3	4	5	6	7	8		
Control	0.183	0.148	0.216	0.199	0.176	0.243	0.213	0.180	0.195	0.000861
100% Effluent	0.153	0.117	0.085	0.153	0.086	0.193	0.137	0.129	0.132	0.00131

9. Equal Variance T Test.

9.1 To perform the t test, calculate the following test statistic:

$$t = \frac{\bar{Y}_1 - \bar{Y}_2}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

Where: \bar{Y}_1 = mean for the control

\bar{Y}_2 = mean for the effluent concentration

$$S_p = \frac{\sqrt{(n_1 - 1) S_1^2 + (n_2 - 1) S_2^2}}{n_1 + n_2 - 2}$$

S_1^2 = estimate of the variance for the control

S_2^2 = estimate of the variance for the effluent concentration

n_1 = number of replicates for the control

n_2 = number of replicates for the effluent concentration

9.2 Since we are usually concerned with a decreased response from the control, such as a decrease in survival or a decrease in reproduction, a one-tailed test is appropriate. Thus, you would compare the calculated t with a critical t, where the critical t is at the 5% level of significance with $n_1 + n_2 - 2$ degrees of freedom. If the calculated t exceeds the critical t, the mean responses are declared different.

9.3 Using the data from Table G.1 to illustrate the t test, the calculation of t is as follows:

$$t = \frac{0.195 - 0.132}{0.0329 \sqrt{\frac{1}{8} + \frac{1}{8}}} = 3.83$$

Where:

$$S_p = \frac{\sqrt{(8-1)0.000861 + (8-1)0.00131}}{8+8-2} = 0.0329$$

9.4 For an 0.05 level of significance test with 14 degrees of freedom, the critical t is 1.762 (Note: Table D.5 for K = 1 includes the critical t values for comparing two groups). Since 3.83 is greater than 1.762, the conclusion is that the growth for the 100% effluent concentration is significantly lower than growth for the control.

10. UNEQUAL VARIANCE T TEST.

10.1 If the F test for equality of variance fails, the t test is still a valid test. However, the denominator of the t statistic is adjusted as follows:

$$t = \frac{\bar{Y}_1 - \bar{Y}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

Where: \bar{Y}_1 = mean for the control

\bar{Y}_2 = mean for the effluent concentration

S_1^2 = estimate of the variance for the control

S_2^2 = estimate of the variance for the effluent concentration

n_1 = number of replicates for the control

n_2 = number of replicates for the effluent concentration

10.2 Additionally, the degrees of freedom for the test are adjusted using the following formula:

$$df' = \frac{(n_1 - 1)(n_2 - 1)}{(n_2 - 1)C^2 + (1 - C)^2(n_1 - 1)}$$

Where:

$$C = \frac{\frac{S_1^2}{n_1}}{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}$$

10.3 The modified degrees of freedom is usually not an integer. Common practice is to round down to the nearest integer.

10.4 The t test is then conducted as the equal variance t test. The calculated t is compared to the critical t at the 0.05 significance level with the modified degrees of freedom. If the calculated t exceeds the critical t, the mean responses are found to be statistically different.

APPENDIX H

PROBIT ANALYSIS

1. This program calculates the EC1 and EC50 (or LC1 and LC50), and the associated 95% confidence intervals.
 2. The program is written in IBM PC Basic for the IBM compatible PC by Computer Sciences Corporation, 26 W. Martin Luther King Drive, Cincinnati, OH 45268. A compiled, executable version of the program and supporting documentation can be obtained from EMSL-Cincinnati by sending a written request to EMSL at 3411 Church Street, Cincinnati, OH 45244.
- 2.1 Data input is illustrated by a set of mortality data (Figure H.1) from a sheepshead minnow embryo-larval survival and teratogenicity test. The program begins with a request for the following information:
1. Desired output of abbreviated (A) or full (F) output? (Note: only abbreviated output is shown below.)
 2. Output designation (P = printer, D = disk file).
 3. Title for the output.
 4. The number of exposure concentrations.
 5. Toxicant concentration data.
- 2.2 The program output for the abbreviated output includes the following:
1. A table of the observed proportion responding and the proportion responding adjusted for the controls (see Figure H.2)
 2. The calculated chi-square statistic for heterogeneity and the tabular value. This test is one indicator of how well the data fit the model. The program will issue a warning when the test indicates that the data do not fit the model.
 3. The estimated LC1 and LC50 values and associated 95% confidence intervals (see Figure H.2).

EPA PROBIT ANALYSIS PROGRAM
USED FOR CALCULATING LC/EC VALUES
Version 1.5

Do you wish abbreviated (A) or full (F) input/output? A

Output to printer (P) or disk file (D)? P

Title ? Example of Probit Analysis

Number responding in the control group = ? 17

Number of animals exposed in the concurrent control group = ? 100

Number of exposure concentrations, exclusive of controls ? 5

Input data starting with the lowest exposure concentration

Concentration = ? 6.25

Number responding = ? 14

Number exposed = ? 100

Concentration = ? 12.5

Number responding = ? 16

Number exposed = ? 102

Concentration = ? 25.0

Number responding = ? 35

Number exposed = ? 100

Concentration = ? 50.0

Number responding = ? 72

Number exposed = ? 99

Concentration = ? 100

Number responding = ? 99

Number exposed = ? 99

<u>Number</u>	<u>Number Conc.</u>	<u>Number Resp.</u>	<u>Exposed</u>
1	6.2500	14	100
2	12.5000	16	102
3	25.0000	35	100
4	50.0000	72	99
5	100.0000	99	99

Do you wish to modify your data ? N

The number of control animals which responded = 17

The number of control animals exposed = 100

Do you wish to modify these values ? N

Figure H.1. Sample Data Input for USEPA Probit Analysis Program, Version 1.5.

Example of Probit Analysis

Conc.	Number Exposed	Number Resp.	Observed Proportion Responding	Proportion Responding Adjusted for Controls
Control	100	17	0.1700	0.0000
6.2500	100	14	0.1400	0.0201
12.5000	102	16	0.1569	0.0001
25.0000	100	35	0.3500	0.2290
50.0000	99	72	0.7273	0.6765
100.0000	99	99	1.0000	1.0000

Chi - Square for Heterogeneity (calculated) = 3.472

Chi - Square for Heterogeneity
(tabular value at 0.05 level) = 7.815

Example of Probit Analysis

Estimated LC/EC Values and Confidence Limits

Point	Exposure Conc.	Lower 95% Confidence Limits	Upper 95% Confidence Limits
LC/EC 1.00	12.917	8.388	16.888
LC/EC 50.00	37.667	32.898	42.081

Figure H.2. USEPA Probit Analysis Program used for Calculating LC/EC Values, Version 1.5.

APPENDIX I

SPEARMAN-KARBER METHOD

1. The Spearman-Karber Method is a nonparametric statistical procedure for estimating the LC50 and the associated 95% confidence interval (Finney, 1978). The Spearman-Karber Method estimates the mean of the distribution of the \log_{10} of the tolerance. If the log tolerance distribution is symmetric, this estimate of the mean is equivalent to an estimate of the median of the log tolerance distribution.
2. If the response proportions are not monotonically non-decreasing with increasing concentration (constant or steadily increasing with concentration), the data must be smoothed. Abbott's procedure is used to "adjust" the concentration response proportions for mortality occurring in the control replicates.
3. Use of the Spearman-Karber Method is recommended when partial mortalities occur in the test solutions, but the data do not fit the Probit model.
4. To calculate the LC50 using the Spearman-Karber Method, the following must be true: 1) the smoothed adjusted proportion mortality for the lowest effluent concentration (not including the control) must be zero, and 2) the smoothed adjusted proportion mortality for the highest effluent concentration must be one.
5. To calculate the 95% confidence interval for the LC50 estimate, one or more of the smoothed adjusted proportion mortalities must be between zero and one.
6. The Spearman-Karber Method is illustrated below using a set of mortality data from a Sheepshead Minnow Larval Survival and Growth test. These data are listed in Table I.1.
7. Let p_0, p_1, \dots, p_k denote the observed response proportion mortalities for the control and k effluent concentrations. The first step is to smooth the p_i if they do not satisfy $p_0 \leq p_1 \leq \dots \leq p_k$. The smoothing process replaces any adjacent p_i 's that do not conform to $p_0 \leq p_1 \leq \dots \leq p_k$ with their average. For example, if p_i is less than p_{i-1} then:

$$p_{i-1}^s = p_i^s = (p_i + p_{i-1})/2$$

Where: p_i^s = the smoothed observed proportion mortality for effluent concentration i .

7.1 For the data in this example, because the observed mortality proportions for the control and the 6.25% effluent concentration are greater than the observed response proportions for the 12.5% and 25.0% effluent concentrations, the responses for these four groups must be averaged:

$$p_0^s = p_1^s = p_2^s = \frac{0.05 + 0.05 + 0.00 + 0.00}{4} = \frac{0.10}{4} = 0.025$$

TABLE I.1. EXAMPLE OF SPEARMAN-KARBER METHOD: MORTALITY DATA FROM A SHEEPSHEAD MINNOW LARVAL SURVIVAL AND GROWTH TEST (40 ORGANISMS PER CONCENTRATION)

Effluent Concentration %	Number of Mortalities	Mortality Proportion
Control	2	0.05
6.25	2	0.05
12.5	0	0.00
25.0	0	0.00
50.0	26	0.65
100.0	40	1.00

7.2 Since $p_4 = 0.65$ is larger than p_3^s , set $p_4^s = 0.65$. Similarly, $p_5 = 1.00$ is larger than p_5^s so set $p_4 = 1.00$. Additional smoothing is not necessary. The smoothed observed proportion mortalities are shown in Table I.2.

TABLE I.2. EXAMPLE OF SPEARMAN-KARBER METHOD: SMOOTHED, ADJUSTED MORTALITY DATA FROM A SHEEPSHEAD MINNOW LARVAL SURVIVAL AND GROWTH TEST

Effluent Concentration %	Mortality Proportion	Smoothed Mortality Proportion	Smoothed, Adjusted Mortality Proportion
Control	0.05	0.025	0.000
6.25	0.05	0.025	0.000
12.5	0.00	0.025	0.000
25.0	0.00	0.025	0.000
50.0	0.65	0.650	0.641
100.0	1.00	1.000	1.000

8. Adjust the smoothed observed proportion mortality in each effluent concentration for mortality in the control group using Abbott's formula (Finney, 1971). The adjustment takes the form:

$$p_i^a = (p_i^s - p_o^s) / (1 - p_o^s)$$

Where : p_o^s = the smoothed observed proportion mortality for the control

p_i^s = the smoothed observed proportion mortality for effluent concentration i.

- 8.1 For the data in this example, the data for each effluent concentration must be adjusted for control mortality using Abbott's formula, as follows:

$$p_o^a = p_1^a = p_2^a = p_3^a = \frac{p_1^s - p_o^s}{1 - p_o^s} = \frac{0.025 - 0.025}{1 - 0.025} = \frac{0.0}{0.975} = 0.0$$

$$p_4^a = \frac{p_4^s - p_o^s}{1 - p_o^s} = \frac{0.650 - 0.025}{1 - 0.025} = \frac{0.625}{0.975} = 0.641$$

$$p_5^a = \frac{p_5^s - p_o^s}{1 - p_o^s} = \frac{1.000 - 0.025}{1 - 0.025} = \frac{0.975}{0.975} = 1.000$$

The smoothed, adjusted response proportions for the effluent concentrations are shown in Table I.2. A plot of the smoothed, adjusted data is shown in Figure I.1.

9. Calculate the \log_{10} of the estimated LC50, m, as follows:

$$m = \sum_{i=1}^k -1 \frac{(p_{i+1}^a) (X_i + X_{i+1})}{2}$$

Where: p_i^a = the smoothed adjusted proportion mortality at concentration i

X_i = the \log_{10} of concentration i

k = the number of effluent concentrations tested, not including the control.

- 9.1 For this example, the \log_{10} of the estimated LC50, m, is calculated as follows:

$$\begin{aligned} m &= [(0.000 - 0.000) (0.7959 + 1.0969)]/2 + \\ &\quad [(0.000 - 0.000) (1.0969 + 1.3979)]/2 + \\ &\quad [(0.641 - 0.000) (1.3979 + 1.6990)]/2 + \\ &\quad [(1.000 - 0.641) (1.6990 + 2.0000)]/2 \\ &= 1.656527 \end{aligned}$$

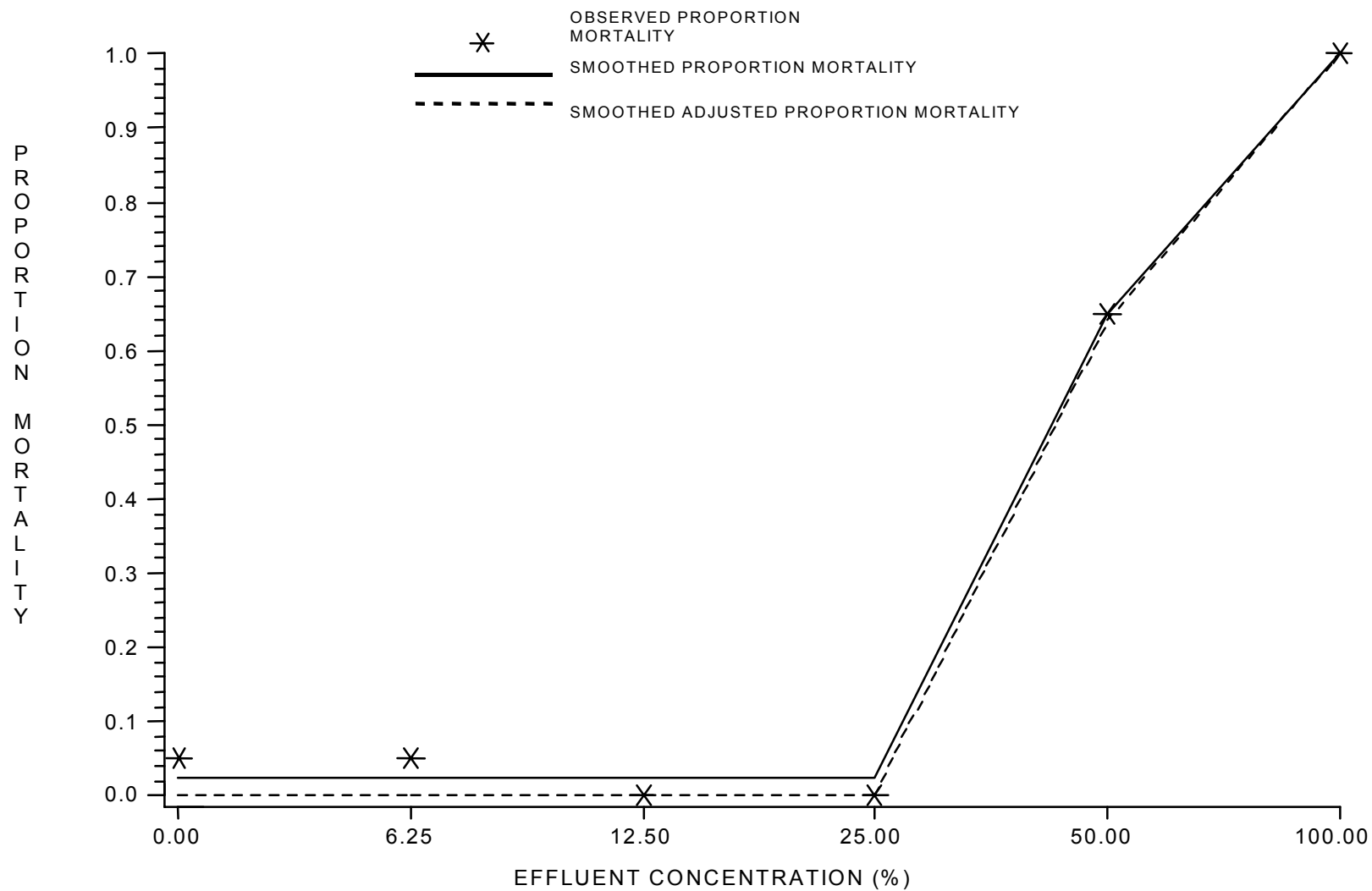


Figure I.1. Plot of observed, smoothed, and adjusted response proportions for sheephead minnow, *Cyprinodon variegatus*, survival data.

10. Calculate the estimated variance of m as follows:

$$V(m) = \sum_{i=2}^k -1 \frac{p_i^a (1-p_i^a) (X_{i+1} + X_{i-1})^2}{4(n_i-1)}$$

Where: X_i = the \log_{10} of concentration i

n_i = the number of organisms tested at effluent concentration i

p_i^a = the smoothed adjusted observed proportion mortality at effluent concentration i

k = the number of effluent concentrations tested, not including the control.

10.1 For this example, the estimated variance of m, $V(m)$, is calculated as follows:

$$\begin{aligned} V(m) &= (0.000)(1.000)(1.3979 - 0.7959)^2/4(39) + \\ &\quad (0.000)(1.000)(1.6990 - 1.0969)^2/4(39) + \\ &\quad (0.641)(0.359)(2.0000 - 1.3979)^2/4(39) \\ &= 0.00053477 \end{aligned}$$

11. Calculate the 95% confidence interval for m: $m \pm 2.0\sqrt{V(m)}$

11.1 For this example, the 95% confidence interval for m is calculated as follows:

$$1.656527 \pm 2\sqrt{0.00053477} = (1.610277, 1.702777)$$

12. The estimated LC50 and a 95% confidence interval for the estimated LC50 can be found by taking base₁₀ antilogs of the above values.

12.1 For this example, the estimated LC50 is calculated as follows:

$$LC50 = \text{antilog}(m) = \text{antilog}(1.656527) = 45.3\%.$$

12.2 The limits of the 95% confidence interval for the estimated LC50 are calculated by taking the antilogs of the upper and lower limits of the 95% confidence interval for m as follows:

$$\text{lower limit: } \text{antilog}(1.610277) = 40.8\%$$

$$\text{upper limit: } \text{antilog}(1.702777) = 50.4\%$$

APPENDIX J

TRIMMED SPEARMAN-KARBER METHOD

1. The Trimmed Spearman-Karber Method is a modification of the Spearman-Karber Method, a nonparametric statistical procedure for estimating the LC50 and the associated 95% confidence interval (Hamilton, et al, 1977). The Trimmed Spearman-Karber Method estimates the trimmed mean of the distribution of the \log_{10} of the tolerance. If the log tolerance distribution is symmetric, this estimate of the trimmed mean is equivalent to an estimate of the median of the log tolerance distribution.
2. If the response proportions are not monotonically non-decreasing with increasing concentration (constant or steadily increasing with concentration), the data must be smoothed. Abbott's procedure is used to "adjust" the concentration response proportions for mortality occurring in the control replicates.
3. Use of the Trimmed Spearman-Karber Method is recommended only when the requirements for the Probit Analysis and the Spearman-Karber Method are not met.
4. To calculate the LC50 using the Trimmed Spearman-Karber Method, the smoothed, adjusted, observed proportion mortalities must bracket 0.5.
5. To calculate the 95% confidence interval for the LC50 estimate, one or more of the smoothed, adjusted, observed proportion mortalities must be between zero and one.
6. Let p_0, p_1, \dots, p_k denote the observed proportion mortalities for the control and the k effluent concentrations. The first step is to smooth the p_i if they do not satisfy $p_0 \leq p_1 \leq \dots \leq p_k$. The smoothing process replaces any adjacent p_i 's that do not conform to $p_0 \leq p_1 \leq \dots \leq p_k$, with their average. For example, if p_i is less than p_{i-1} then:

Where: $p_{i-1}^s = p_i^s = (p_i + p_{i-1})/2$

p_i^s = the smoothed observed proportion mortality for effluent concentration i .

7. Adjust the smoothed observed proportion mortality in each effluent concentration for mortality in the control group using Abbott's formula (Finney, 1971). The adjustment takes the form:

Where: $p_i^a = (p_i^s - p_o^s)/(1 - p_o^s)$

p_o^s = the smoothed observed proportion mortality for the control

p_i^s = the smoothed observed proportion mortality for effluent concentration i .

8. Calculate the amount of trim to use in the estimation of the LC50 as follows:

Where: Trim = maximum $p_1^a, (1 - p_k^a)$

p_1^a = the smoothed, adjusted proportion mortality for the lowest effluent concentration, exclusive of the control

p_k^a = the smoothed, adjusted proportion mortality for the highest effluent concentration

k = the number of effluent concentrations, exclusive of the control.

The minimum trim should be calculated for each data set rather than using a fixed amount of trim for each data set.

9. Due to the intensive nature of the calculation for the estimated LC50 and the calculation of the associated 95% confidence interval using the Trimmed Spearman-Kärber Method, it is recommended that the data be analyzed by computer.

10. A computer program which estimates the LC50 and associated 95% confidence interval using the Trimmed Spearman-Kärber Method, can be obtained through the EMSL, 3411 Church Street, Cincinnati, OH 45244. The program can be obtained from EMSL-Cincinnati by sending a written request to the above address.

11. The Trimmed Spearman-Kärber program automatically performs the following functions:

- a. Smoothing.
- b. Adjustment for mortality in the control.
- c. Calculation of the necessary trim.
- d. Calculation of the LC50.
- e. Calculation of the associated 95% confidence interval.

12. To illustrate the Trimmed Spearman-Kärber method using the Trimmed Spearman-Kärber computer program, a set of data from a Sheepshead Minnow Larval Survival and Growth test will be used. The data are listed in Table J.1.

12.1 The program requests the following input (Figure J.1):

- a. Output destination (D = disk file or P = printer).
- b. Control data.
- c. Data for each toxicant concentration.

12.2 The program output includes the following (Figure J.2):

- a. A table of the concentrations tested, number of organisms exposed, and the mortalities.
- b. The amount of trim used in the calculation.
- c. The estimated LC50 and the associated 95% confidence interval.

TABLE J.1. EXAMPLE OF TRIMMED SPEARMAN-KÄRBER METHOD: MORTALITY DATA FROM A SHEEPSHEAD MINNOW LARVAL SURVIVAL AND GROWTH TEST (40 ORGANISMS PER CONCENTRATION)

Effluent Concentration %	Number of Mortalities	Mortality Proportion
Control	2	0.05
6.25	0	0.00
12.5	2	0.05
25.0	0	0.00
50.0	0	0.00
100.0	32	0.80

A:>TSK

TRIMMED SPEARMAN-KARBER METHOD. VERSION 1.5

ENTER DATE OF TEST:

1

ENTER TEST NUMBER:

2

WHAT IS TO BE ESTIMATED?

(ENTER "L" FOR LC50 AND "E" FOR EC50)

L

ENTER TEST SPECIES NAME:

Sheepshead minnow

ENTER TOXICANT NAME:

effluent

ENTER UNITS FOR EXPOSURE CONCENTRATION OF TOXICANT :

%

ENTER THE NUMBER OF INDIVIDUALS IN THE CONTROL:

40

ENTER THE NUMBER OF MORTALITIES IN THE CONTROL:

2

ENTER THE NUMBER OF CONCENTRATIONS

(NOT INCLUDING THE CONTROL; MAXIMUM = 10):

5

ENTER THE 5 EXPOSURE CONCENTRATIONS (IN INCREASING ORDER):

6.25 12.5 25 50 100

ARE THE NUMBER OF INDIVIDUALS AT EACH EXPOSURE CONCENTRATION EQUAL(Y/N)?

y

ENTER THE NUMBER OF INDIVIDUALS AT EACH EXPOSURE CONCENTRATION:

40

ENTER UNITS FOR DURATION OF EXPERIMENT

(ENTER "H" FOR HOURS, "D" FOR DAYS, ETC.):

Days

ENTER DURATION OF TEST:

7

ENTER THE NUMBER OF MORTALITIES AT EACH EXPOSURE CONCENTRATION:

0 2 0 0 32

WOULD YOU LIKE THE AUTOMATIC TRIM CALCULATION(Y/N)?

y

Figure J.1. Example input for Trimmed Spearman-Kärber Method.

TRIMMED SPEARMAN-KARBER METHOD. VERSION 1.5

DATE: 1 TEST NUMBER: 2 DURATION: 7 Days TOXICANT:
 effluent
 SPECIES: sheepshead minnow

RAW DATA:	Concentration	Number (%)	Mortalities Exposed
---	.00	40	2
	6.25	40	0
	12.50	40	2
	25.00	40	0
	50.00	40	0
	100.00	40	32

SPEARMAN-KARBER TRIM: 20.41%

SPEARMAN-KARBER ESTIMATES: LC50: 77.28
 95% CONFIDENCE LIMITS
 ARE NOT RELIABLE.

NOTE: MORTALITY PROPORTIONS WERE NOT MONOTONICALLY INCREASING.
 ADJUSTMENTS WERE MADE PRIOR TO SPEARMAN-KARBER ESTIMATION.

Figure J.2. Example output for Trimmed Spearman-Karber Method.

APPENDIX K

GRAPHICAL METHOD

1. The Graphical Method is used to calculate the LC50. It is a mathematical procedure which estimates the LC50 by linearly interpolating between points of a plot of observed percent mortality versus the base 10 logarithm (\log_{10}) of percent effluent concentration. This method does not provide a confidence interval for the LC50 estimate and its use is only recommended when there are no partial mortalities. The only requirement for the Graphical Method is that the observed percent mortalities bracket 50%.
2. For an analysis using the Graphical Method the data must first be smoothed and adjusted for mortality in the control replicates. The procedure for smoothing and adjusting the data is detailed in the following steps.
3. The Graphical Method is illustrated below using a set of mortality data from an Inland Silverside Larval Survival and Growth test. These data are listed in Table K.1.

TABLE K.1. EXAMPLE OF GRAPHICAL METHOD: MORTALITY DATA FROM AN INLAND SILVERSIDE LARVAL SURVIVAL AND GROWTH TEST (40 ORGANISMS PER CONCENTRATION)

Effluent Concentration %	Number of Mortalities	Mortality Proportion
Control	2	0.05
6.25	0	0.00
12.5	0	0.00
25.0	0	0.00
50.0	40	1.00
100.0	40	1.00

4. Let p_0, p_1, \dots, p_k denote the observed proportion mortalities for the control and the k effluent concentrations. The first step is to smooth the p_i if they do not satisfy $p_0 \leq p_1 \leq \dots \leq p_k$. The smoothing process replaces any adjacent p_i 's that do not conform to $p_0 \leq p_1 \leq \dots \leq p_k$ with their average. For example, if p_i is less than p_{i-1} then:

Where: $p_{s-1}^s = p_i^s = (p_i + p_{i-1})/2$

p_i^s = the smoothed observed proportion mortality for effluent concentration i .

4.1 For the data in this example, because the observed mortality proportions for the 6.25%, 12.5%, and 25.0% effluent concentrations are less than the observed response proportion for the control, the values for these four groups must be averaged:

$$p_o^s = p_1^s = p_2^s = p_3^s = \frac{0.05+0.00+0.00+0.00}{4} = \frac{0.05}{4} = 0.0125$$

4.2 Since $p_4 = p_5 = 1.00$ are larger than 0.0125, set $p_4^s = p_5^s = 1.00$. Additional smoothing is not necessary. The smoothed observed proportion mortalities are shown in Table K.2.

5. Adjust the smoothed observed proportion mortality in each effluent concentration for mortality in the control group using Abbott's formula (Finney, 1971). The adjustment takes the form:

Where: $p_1^a = (p_1^s - p_o^s) / (1 - p_o^s)$

p_o^s = the smoothed observed proportion mortality for the control

p_i^s = the smoothed observed proportion mortality for effluent concentration i.

5.1 Because the smoothed observed proportion mortality for the control group is greater than zero, the responses must be adjusted using Abbott's formula, as follows:

$$p_o^a = p_1^a = p_2^a = p_3^a = \frac{p_1^s - p_o^s}{1 - p_o^s} = \frac{0.0125 - 0.0125}{1 - 0.0125} = \frac{0.0}{0.9875} = 0.0$$

$$p_4^a = p_5^a = \frac{p_4^s - p_o^s}{1 - p_o^s} = \frac{1.00 - 0.0125}{1 - 0.0125} = \frac{0.9875}{0.9875} = 1.00$$

A table of the smoothed, adjusted response proportions for the effluent concentrations are shown in Table K.2.

5.2 Plot the smoothed, adjusted data on 2-cycle semi-log graph paper with the logarithmic axis (the y axis) used for percent effluent concentration and the linear axis (the x axis) used for observed percent mortality. A plot of the smoothed, adjusted data is shown in Figure K.1.

TABLE K.2. EXAMPLE OF GRAPHICAL METHOD: SMOOTHED, ADJUSTED MORTALITY DATA FROM AN INLAND SILVERSIDE LARVAL SURVIVAL AND GROWTH TEST

Effluent Concentration %	Mortality Proportion	Smoothed Mortality Proportion	Smoothed Adjusted Mortality Proportion
Control	0.05	0.0125	0.00
6.25	0.00	0.0125	0.00
12.5	0.00	0.0125	0.00
25.0	0.00	0.0125	0.00
50.0	1.00	1.0000	1.00
100.0	1.00	1.0000	1.00

6. Locate the two points on the graph which bracket 50% mortality and connect them with a straight line.
 7. On the scale for percent effluent concentration, read the value for the point where the plotted line and the 50% mortality line intersect. This value is the estimated LC50 expressed as a percent effluent concentration.
- 7.1 For this example, the two points on the graph which bracket the 50% mortality line (0% mortality at 25% effluent, and 100% mortality at 50% effluent) are connected with a straight line. The point at which the plotted line intersects the 50% mortality line is the estimated LC50. The estimated LC50 = 35% effluent.

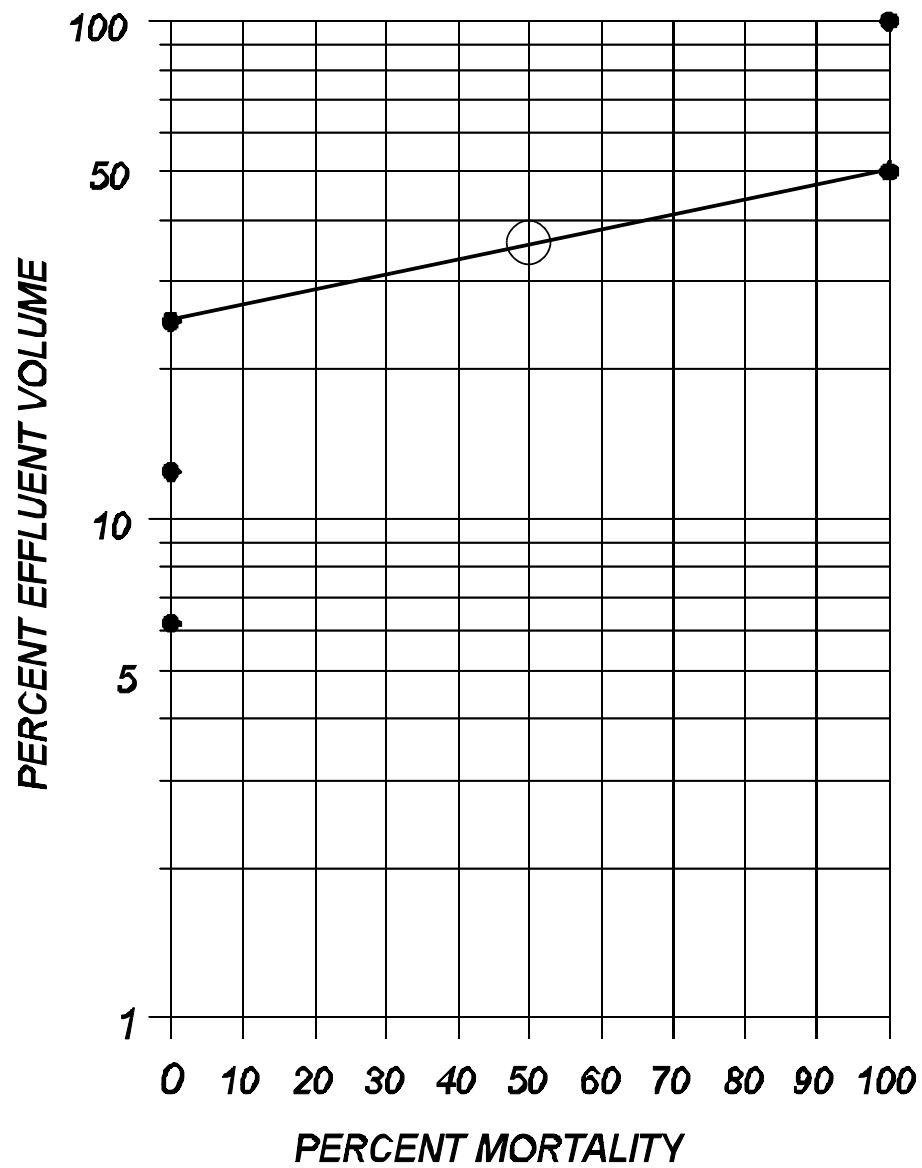


Figure K.1. Plot of the smoothed adjusted response proportions for inland silverside, *Menidia beryllina*, survival data.

APPENDIX L

LINEAR INTERPOLATION METHOD

1. GENERAL PROCEDURE

1.1 The Linear Interpolation Method is used to calculate a point estimate of the effluent or other toxicant concentration that causes a given percent reduction (e.g., 25%, 50%, etc.) in the reproduction or growth of the test organisms (Inhibition Concentration, or IC). The procedure was designed for general applicability in the analysis of data from short-term chronic toxicity tests, and the generation of an endpoint from a continuous model that allows a traditional quantitative assessment of the precision of the endpoint, such as confidence limits for the endpoint of a single test, and a mean and coefficient of variation for the endpoints of multiple tests.

1.2 The Linear Interpolation Method assumes that the responses (1) are monotonically non-increasing, where the mean response for each higher concentration is less than or equal to the mean response for the previous concentration, (2) follow a piecewise linear response function, and (3) are from a random, independent, and representative sample of test data. If the data are not monotonically non-increasing, they are adjusted by smoothing (averaging). In cases where the responses at the low toxicant concentrations are much higher than in the controls, the smoothing process may result in a large upward adjustment in the control mean. Also, no assumption is made about the distribution of the data except that the data within a group being resampled are independent and identically distributed.

2. DATA SUMMARY AND PLOTS

2.1 Calculate the mean responses for the control and each toxicant concentration, construct a summary table, and plot the data.

3. MONOTONICITY

3.1 If the assumption of monotonicity of test results is met, the observed response means (\bar{Y}_i) should stay the same or decrease as the toxicant concentration increases. If the means do not decrease monotonically, the responses are "smoothed" by averaging (pooling) adjacent means.

3.2 Observed means at each concentration are considered in order of increasing concentration, starting with the control mean (\bar{Y}_1). If the mean observed response at the lowest toxicant concentration (\bar{Y}_2) is equal to or smaller than the control mean (\bar{Y}_1), it is used as the response. If it is larger than the control mean, it is averaged with the control, and this average is used for both the control response (M_1) and the lowest toxicant concentration response (M_2). This mean is then compared to the mean observed response for the next higher toxicant concentration (\bar{Y}_3). Again, if the mean observed response for the next higher toxicant concentration is smaller than the mean of the control and the lowest toxicant concentration, it is used as the response. If it is higher than the mean of the first two, it is averaged with the first two, and the mean is used as the response for the control and two lowest concentrations of toxicant. This process is continued for data from the remaining toxicant concentrations. A numerical example of smoothing the data is provided below. (Note: Unusual patterns in the deviations from monotonicity may require an additional step of smoothing). Where \bar{Y}_i decrease monotonically, the \bar{Y}_i become M_i without smoothing.

4. LINEAR INTERPOLATION METHOD

4.1 The method assumes a linear response from one concentration to the next. Thus, the IC_p is estimated by linear interpolation between two concentrations whose responses bracket the response of interest, the (p) percent reduction from the control.

4.2 To obtain the estimate, determine the concentrations C_J and C_{J+1} which bracket the response $M_1(1 - p/100)$, where M_1 is the smoothed control mean response and p is the percent reduction in response relative to the control response. These calculations can easily be done by hand or with a computer program as described below. The linear interpolation estimate is calculated as follows:

$$ICp = C_J + [M_1(1 - p/100) - M_J'] \frac{(C_{J+1} - C_J)}{(M_{J+1} - M_J)}$$

Where: C_J = tested concentration whose observed mean response is greater than $M_1(1 - p/100)$.

C_{J+1} = tested concentration whose observed mean response is less than $M_1(1 - p/100)$.

M_1 = smoothed mean response for the control.

M_J = smoothed mean response for concentration J .

M_{J+1} = smoothed mean response for concentration $J + 1$.

p = percent reduction in response relative to the control response.

ICp = estimated concentration at which there is a percent reduction from the smoothed mean control response. The ICp is reported for the test, together with the 95% confidence interval calculated by the ICPIN.EXE program described below.

4.3 If the C_J is the highest concentration tested, the ICp would be specified as *greater than* C_J . If the response at the lowest concentration tested is used to extrapolate the ICp value, the ICp should be expressed as a *less than the lowest test concentration*.

5. CONFIDENCE INTERVALS

5.1 Due to the use of a linear interpolation technique to calculate an estimate of the ICp , standard statistical methods for calculating confidence intervals are not applicable for the ICp . This limitation is avoided by use a technique known as the bootstrap method as proposed by Efron (1982) for deriving point estimates and confidence intervals.

5.2 In the Linear Interpolation Method, the smoothed response means are used to obtain the ICp estimate reported for the test. The bootstrap method is used to obtain the 95% confidence interval for the true mean. In the bootstrap method, the test data Y_{ji} is randomly resampled with replacement to produce a new set of data Y_{ji}^* , that is statistically equivalent to the original data, but a new and slightly different estimate of the ICp (ICp^*) is obtained. This process is repeated at least 80 times (Marcus and Holtzman, 1988) resulting in multiple "data" sets, each with an associate ICp^* estimate. The distribution of the ICp^* estimates derived from the sets of resampled data approximates the sampling distribution of the ICp estimate. The standard error of the ICp is estimated by the standard deviation of the individual ICp^* estimates. Empirical confidence intervals are derived from the quantiles of the ICp^* empirical distribution. For example, if the test data are resampled a minimum of 80 times, the empirical 2.5% and the 97.5% confidence limits are approximately the second smallest and second largest ICp^* estimates (Marcus and Holtzman, 1988).

5.3 The width of the confidence intervals calculated by the bootstrap method is related to the variability of the data. When confidence intervals are wide, the reliability of the IC estimate is in question. However, narrow intervals do

not necessarily indicate that the estimate is highly reliable, because of undetected violations of assumptions and the fact that the confidence limits based on the empirical quantiles of a bootstrap distribution of 80 samples may be unstable.

5.4 The bootstrapping method of calculating confidence intervals is computationally intensive. For this reason, all of the calculations associated with determining the confidence intervals for the ICp estimate have been incorporated into a computer program. Computations are most easily done with a computer program such as the revision of the BOOTSTRP program (USEPA, 1988; USEPA, 1989) which is now called "ICPIN" which is described below in Subsection 7.

6. MANUAL CALCULATIONS

6.1 DATA SUMMARY AND PLOTS

6.1.1 The data used in this example are the mysid growth data used in the example in Section 14. The data is presented as the mean weight per original number of organisms. Table L.1 includes the raw data and the mean growth for each concentration. A plot of the data is provided in Figure L.1.

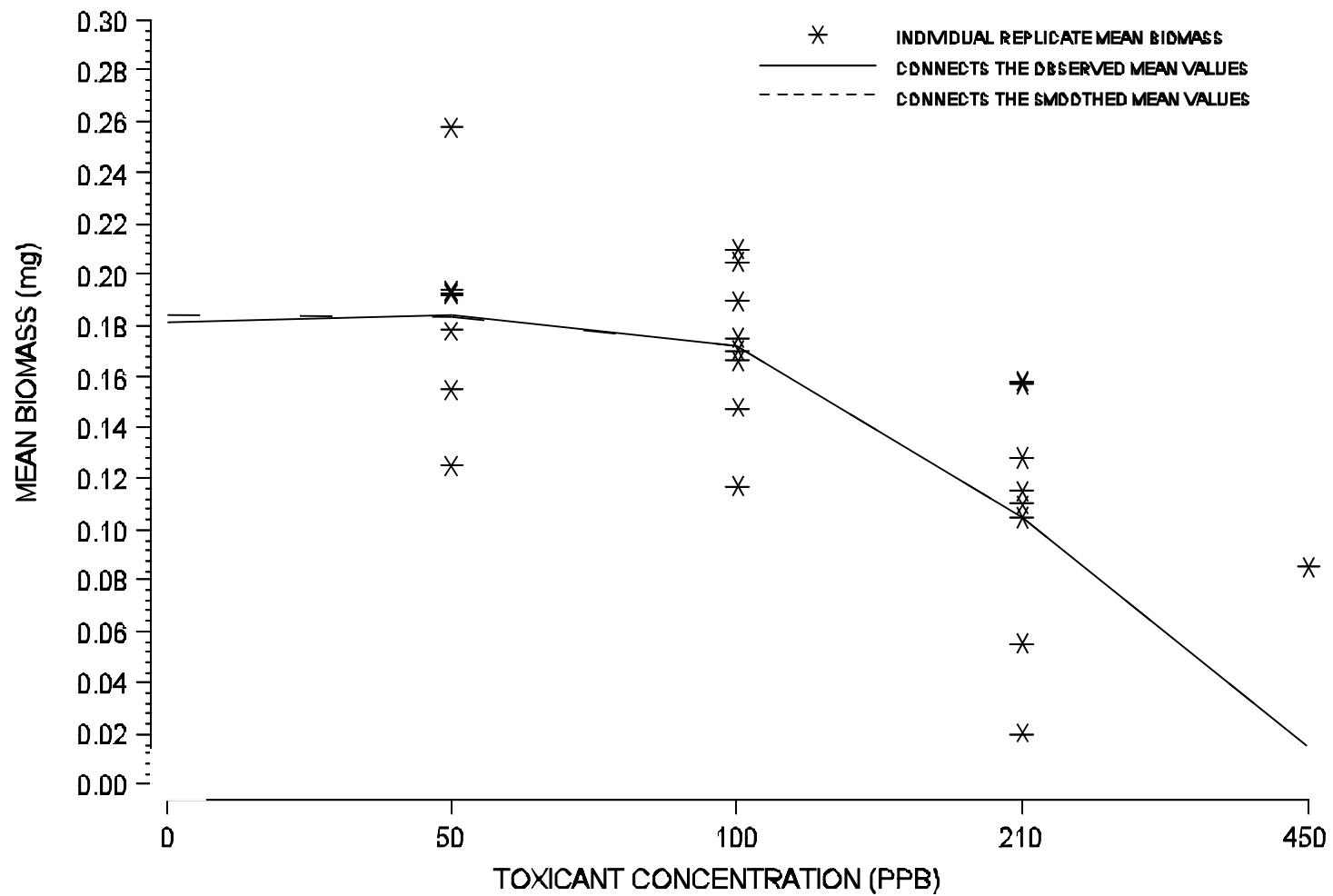


Figure L.1. Plot of raw data, observed means, and smoothed means for the mysid, *Mysidopsis bahia*, growth data.

TABLE L.1. MYSID, *MYSIDOPSIS BAHIA*, GROWTH DATA

Replicate	Control	<u>Toxicant Concentration (ppb)</u>			
		50	100	210	450
1	0.146	0.154	0.114	0.153	0
2	0.118	0.193	0.172	0.094	0.012
3	0.216	0.190	0.160	0.017	0
4	0.199	0.190	0.199	0.122	0.002
5	0.176	0.256	0.165	0.052	0
6	0.243	0.191	0.145	0.154	0
7	0.213	0.122	0.207	0.110	0
8	0.144	0.177	0.186	0.103	0.081
Mean (\bar{Y}_i)	0.182	0.184	0.168	0.101	0.012
i	1	2	3	4	5

6.2 MONOTONICITY

6.2.1 As can be seen from the plot in Figure L.1, the observed means are not monotonically non-increasing with respect to concentration. Therefore, the means must be smoothed prior to calculating the IC.

6.2.2 Starting with the control mean $\bar{Y}_1 = 0.186$ and $\bar{Y}_2 = 0.184$, we see that $\bar{Y}_1 < \bar{Y}_2$. Calculate the smoothed means:

$$M_1 = M_2 = (\bar{Y}_1 + \bar{Y}_2)/2 = 0.193$$

6.2.3 Since $\bar{Y}_5 = 0.025 < \bar{Y}_4 = 0.101 < \bar{Y}_3 = 0.168 < M_2$, set $M_3 = 0.168$ and $M_4 = 0.101$, and $M_5 = 0.025$. Table L.2 contains the smoothed means and Figure L.1 gives a plot of the smoothed response curve.

6.3 LINEAR INTERPOLATION

6.3.1 Estimates of the IC25 and IC50 can be calculated using the Linear Interpolation Method. A 25% reduction in mean weight, compared to the controls, would result in a mean weight of 0.139, where $M_1(1-p/100) = 0.185(1-25/100)$. A 50% reduction in mean weight, compared to the controls, would result in a mean weight of 0.093 mg. Examining the smoothed means and their associated concentrations (Table L.2), the two effluent concentrations bracketing the mean weight per original of 0.139 mg are $C_3 = 100$ ppb and $C_4 = 210$ ppb. The two effluent concentrations bracketing a response of 0.093 mg per total original number of organisms are $C_4 = 210$ ppb and $C_5 = 450$ ppb.

TABLE L.2. MYSID, *MYSIDOPSIS BAHIA*, MEAN GROWTH RESPONSE AFTER SMOOTHING

Toxicant Conc. (ppb)	i	Smoothed Mean M_i (mg)
Control	1	0.183
50	2	0.183
100	3	0.168
210	4	0.101
450	5	0.025

6.3.2 Using the equation from section 4.2, the estimate of the IC25 is calculated as follows:

$$ICp = C_j + [M_1(1 - 1p/100) - M_j'] \frac{(C_{j+1} - C_j)}{(M_{j+1} - M_j)}$$

$$IC25 = 100 + [0.93(1 - 25/100) - 0.164] \frac{(210 - 100)}{(0.101 - 0.164)}$$

$$= 151 \text{ ppb}$$

6.3.3 Using Equation 1 from 4.2, the estimate of the IC50 is calculated as follows:

$$ICp = C_j + [M_1(1 - 1p/100) - M_j'] \frac{(C_{j+1} - C_j)}{(M_{j+1} - M_j)}$$

$$IC50 = 210 + [210 + [0.193(1 - 50/100) - 0.101] \frac{(450 - 210)}{(0.028 - 0.101)}$$

$$= 239 \text{ ppb}$$

6.4 CONFIDENCE INTERVALS

6.4.1 Confidence intervals for the ICp are derived using the bootstrap method. As described above, this method involves randomly resampling the individual observations and recalculating the ICp at least 80 times, and determining the mean ICp, standard deviation, and empirical 95% confidence intervals. For this reason, the confidence intervals are calculated using a computer program called ICPIN. This program is described below and is available to carry out all the calculations of both the interpolation estimate (ICp) and the confidence intervals.

7. COMPUTER CALCULATIONS

7.1 The computer program, ICPIN, prepared for the Linear Interpolation Methods was written in TURBO PASCAL for IBM compatible PCS. The program (version 2.0) has been modified by Computer Science Corporation, Duluth, MN with funding provided by the Environmental Research Laboratory, Duluth, MN (Norberg-King, 1993). The program was originally developed by Battelle Laboratories, Columbus, OH through a government contract supported by the Environmental Research Laboratory, Duluth, MN (USEPA, 1988). A compiled, executable version of the program and supporting documentation can be obtained by sending a written request to EMSL-Cincinnati, 3411 Church Street, Cincinnati, OH 45244.

7.2 The ICPIN.EXE program performs the following functions: 1) it calculates the observed response means (\bar{y}) (response means); 2) it calculates the standard deviations; 3) checks the responses for monotonicity; 4) calculates smoothed means (M_i) (pooled response means) if necessary; 5) uses the means, M_i , to calculate the initial IC_p of choice by linear interpolation; 6) performs a user-specified number of bootstrap resamples between 80 and 1000 (as multiples of 40); 7) calculates the mean and standard deviation of the bootstrapped IC_p estimates; and 8) provides an original 95% confidence intervals to be used with the initial IC_p when the number of replicates per concentration is over six and provides both original and expanded confidence intervals when the number of replicates per concentration are less than seven (Norberg-King, 1993).

7.3 For the IC_p calculation, up to twelve treatments can be input (which includes the control). There can be up to 40 replicates per concentration, and the program does not require an equal number of replicates per concentration. The value of p can range from 1% to 99%.

7.4 DATA INPUT

7.4.1 Data is entered directly into the program onscreen. A sample data entry screen is shown in Figure L.2. The program documentation provides guidance on the entering and analysis of data for the Linear Interpolation Method.

7.4.2 The user selects the IC_p estimate desired (e.g., IC₂₅ or IC₅₀) and the number of resamples to be taken for the bootstrap method of calculating the confidence intervals. The program has the capability of performing any number of resamples from 80 to 1000 as multiples of 40. However, Marcus and Holtzman (1988) recommend a minimum of 80 resamples for the bootstrap method be used and at least 250 resamples are better (Norberg-King, 1993).

ICp Data Entry/Edit Screen		Current File:				
Conc. ID	1	2	3	4	5	6
Conc. Tested						
Response 1						
Response 2						
Response 3						
Response 4						
Response 5						
Response 6						
Response 7						
Response 8						
Response 9						
Response 10						
Response 11						
Response 12						
Response 13						
Response 14						
Response 15						
Response 16						
Response 17						
Response 18						
Response 19						
Response 20						

F10 for Command Menu

Use Arrow Keys to Switch Fields

Figure L.2. ICp data entry/edit screen. Twelve concentration identifications can be used. Data for concentrations are entered in columns 1 through 6. For concentrations 7 through 12 and responses 21-40 the data is entered in additional fields of the same screen.

7.5 DATA OUTPUT

7.5.1 The program output includes the following (Figures L.3 and L.4)

1. A table of the concentration identification, the concentration tested and raw data response for each replicate and concentration.
2. A table of test concentrations, number of replicates, concentration (units), response means (Y_i), standard deviations for each response mean, and the pooled response means (smoothed means; M_i).
3. The linear interpolation estimate of the IC_p using the means (M_i). *Use this value for the IC_p estimate.*
4. The mean IC_p and standard deviation from the bootstrap resampling.
5. The confidence intervals calculated by the bootstrap method for the IC_p. Provides an original 95% confidence intervals to be used with the initial IC_p when the number of replicates per concentration is over six and provides both original and expanded confidence intervals when the number of replicates per concentration are less than seven.

7.6 ICPIN program output for the analysis of the mysid growth data in Table L.1 is provided in Figures L.3 and L.4.

7.6.1 When the ICPIN program was used to analyze this set of data, requesting 80 resamples, the estimate of the IC₂₅ was 133.5054 (ppb). The empirical 95% confidence intervals for the true mean was 96.8623 to 186.6383 (ppb).

7.6.2 When the ICPIN program was used to analyze this set of data, requesting 80 resamples, the estimate of the IC₅₀ was 234.6761 (ppb). The empirical 95% confidence intervals for the true mean were 184.8692 to 283.3965 (ppb).

Conc. ID	1	2	3	4.	5
Conc. Tested	0	50	100	210	450
Response 1	.146	.154	.114	.153	0
Response 2	.118	.193	.172	.094	.012
Response 3	.216	.190	.160	.017	0
Response 4	.199	.190	.199	.122	.002
Response 5	.176	.256	.165	.052	0
Response 6	.243	.191	.145	.154	0
Response 7	.213	.122	.207	.110	0
Response 8	.144	.177	.186	.103	.081

*** Inhibition Concentration Percentage Estimate ***

Toxicant/Effluent:

Test Start Date: Test Ending Date:

Test Species: MYSID SHRIMP, Mysidopsis bahia

Test Duration: growth test

DATA FILE: mysidwt.icp

OUTPUT FILE: mysid.i25

Conc. ID	Number Replicates	Concentration $\mu\text{g/l}$	Response Means	Standard. Dev.	Pooled Response Means
1	8	0.000	0.182	0.043	0.183
2	8	50.000	0.184	0.038	0.183
3	8	100.000	0.168	0.030	0.168
4	8	210.000	0.101	0.047	0.101
5	8	450.000	0.012	0.028	0.012

The Linear Interpolation Estimate: 133.5054 Entered P Value: 25

Number of Resamplings: 80

The Bootstrap Estimates Mean: 147.1702 Standard Deviation: 23.7984

Original Confidence Limits: Lower: 96.8623 Upper: 186.6383

Resampling time in Seconds: 0.16 Random Seed: -1623038650

Figure L.3. Example of ICPIN program output for the IC25.

Conc. ID	1	2	3	4.	5
Conc. Tested	0	50	100	210	450
Response 1	.146	.154	.114	.153	0
Response 2	.118	.193	.172	.094	.012
Response 3	.216	.190	.160	.017	0
Response 4	.199	.190	.199	.122	.002
Response 5	.176	.256	.165	.052	0
Response 6	.243	.191	.145	.154	0
Response 7	.213	.122	.207	.110	0
Response 8	.144	.177	.186	.103	.081

*** Inhibition Concentration Percentage Estimate ***

Toxicant/Effluent:

Test Start Date: Test Ending Date:

Test Species: MYSID SHRIMP, Mysidopsis bahia

Test Duration: growth test

DATA FILE: mysidwt.icp

OUTPUT FILE: mysidwt.i50

Conc. ID	Number Replicates	Concentration $\mu\text{g/L}$	Response Means	Standard. Dev.	Pooled Response Means
1	8	0.000	0.182	0.043	0.183
2	8	50.000	0.184	0.038	0.183
3	8	100.000	0.168	0.030	0.168
4	8	210.000	0.101	0.047	0.101
5	8	450.000	0.012	0.028	0.012

The Linear Interpolation Estimate: 234.6761 Entered P Value: 50

Number of Resamplings: 80

The Bootstrap Estimates Mean: 233.3311 Standard Deviation: 28.9594

Original Confidence Limits: Lower: 184.8692 Upper: 283.3965

Resampling time in Seconds: 0.11 Random Seed: 1103756486

Figure L.4. Example ICPIN program output for the IC50.

CITED REFERENCES

- Bartlett, M.S. 1937. Some examples of statistical methods of research in agriculture and applied biology. *J. Royal Statist. Soc. Suppl.* 4:137-183.
- Conover, W.J. 1980. *Practical nonparametric statistics*. Second edition. John Wiley and Sons, NY, NY. pp. 466-467.
- Dixon, W.J., and F.J. Massey, Jr. 1983. *Introduction to statistical analysis*. Fourth Edition. McGraw Hill, NY, NY.
- Draper, N.R., and J.A. John. 1981. Influential observations and outliers in regression. *Technometrics* 23:21-21.
- Dunnnett, C.W. 1955. Multiple comparison procedure for comparing several treatments with a control. *J. Amer. Statist. Assoc.* 50:1096-1121.
- Dunnnett, C.W. 1964. New table for multiple comparisons with a control. *Biometrics* 20:482.
- Efron, B. 1982. The Jackknife, the Bootstrap, and other resampling plans. *CBMS* 38, Soc. Industr. Appl. Math., Philadelphia, PA.
- Finney, D.J. 1971. *Probit analysis*. Third Edition. Cambridge Press, NY, NY. 668 pp.
- Finney, D.J. 1978. *Statistical method in biological assay*. Third Edition. Charles Griffin & Co. Ltd, London, England. 508 pp.
- Hamilton, M.A., R.C. Russo, and R.V. Thurston. 1977. Trimmed Spearman-Kärber method for estimating median lethal concentrations. *Environ. Sci. Tech.* 11(7):714-719.
- Marcus, A.H., and A.P. Holtzman. 1988. A robust statistical method for estimating effects concentrations in short-term fathead minnow toxicity tests. Manuscript submitted to the Criteria and Standards Division, U. S. Environmental Protection Agency, by Battelle Washington Environmental Program Office, Washington, DC. June 1988 under EPA Contract No. 69-03-3534. 39 pp.
- Miller, R.G. 1981. *Simultaneous statistical inference*. Springer-Verlag, New York, NY. 299 pp.
- Norberg-King, T.J. 1993. A linear interpolation method for sublethal toxicity: The inhibition concentration (IC_p) approach. Version 2.0. National Effluent Toxicity Assessment Center Technical Report 03-93, Environmental Research Laboratory, Duluth, MN 55804. June 1993.
- Scheffe, H. 1959. *The analysis of variance*. John Wiley, New York. 477 pp.
- Snedecor, G.W., and W.G. Cochran. 1980. *Statistical Methods*. Seventh edition. Iowa State University Press, Ames, IA. 593 pp.
- Steel, R.G. 1959. A multiple comparison rank sum test: treatments versus control. *Biometrics* 15:560-572.
- Stephens, M.A. 1974. EDF statistics for goodness of fit and some comparisons. *J. Amer. Stat. Assoc. (JASA)* 69:730-7737.
- USEPA. 1988. An interpolation estimate for chronic toxicity: The IC_p approach. Norberg-King, T.J. Technical Report 05-88, National Effluent Toxicity Assessment Center, Environmental Research Laboratory, U. S. Environmental Protection Agency, Duluth, MN 55804.

- USEPA. 1989. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms. Second Edition. Weber, C.I., W.H. Peltier, T.J. Norberg-King, W.B. Horning, II, F.A. Kessler, J.R. Menkedick, T.W. Neiheisel, P.A. Lewis, D.J. Klemm, Q.H. Pickering, E.L. Robinson, J.M. Lazorchak, L.J. Wymer, and R.W. Freyberg (eds.). Environmental Monitoring Systems Laboratory, U. S. Environmental Protection Agency, Cincinnati, OH 45268. EPA/600/4-89/001.
- USEPA. 1993. Methods for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms. Fourth Edition. Weber, C.I. (ed.). Environmental Monitoring Systems Laboratory, U. S. Environmental Protection Agency, Cincinnati, OH 45268. EPA/600/4-90/027F.